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13. ABSTRACT

Possible problems for human performance in relation to three factors, motivation, cognition, and sleep, are discussed. Of particular concern in the discussion are possible alterations in cycles of sleeping and waking, and in physiological patterns of sleep and the potential effects of such changes on vigilance, memory, problem solving, and motivation. An attempt is also made to anticipate the effects of prolonged space-flights on the central and autonomic nervous systems.

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5 Motivation, Cognition, and Sleep-Work Factors; Central- and Autonomic-Nervous-System Indices

This chapter discusses possible problems for human performance in relation to three factors—motivation, cognition, and sleep. Of particular concern are possible alterations in cycles of sleeping and waking and in physiological patterns of sleep and the potential effects of such changes on vigilance, memory, problem-solving, and motivation. It is assumed that critical environmental factors such as the cabin atmosphere, food and water, and the medical and psychiatric health of the crew, will be adequately controlled.

As with other aspects of man's functioning during long-duration space missions, the relevance to spaceflight of published laboratory and simulator studies of performance and psychophysiological factors is not known. The most significant limitation is that no study even approaches the durations contemplated for long-term missions. However, some of the findings from investigations of social isolation, sensory deprivation, and sleep deprivation, from reports of wintering-over parties in the Antarctic, and from long submarine voyages point to areas of potential difficulty. [See Schultz (1965) and Zubek (1969b) for excellent summaries of the effects of sensory restriction.]

Contributors to this chapter are L. C. Johnson, H. L. Williams, and J. A. Stern.

Brownfield (1965) emphasized that the different kinds of isolation may alter the environment in four important ways. The isolated individual or group may be (1) confined to a limited space; (2) separated from highly valued persons, places, or things; (3) exposed to sharply reduced sensory stimulation; or (4) exposed to reduction in the variability and patterning of stimulation to such an extent that important aspects of stimulation may no longer be perceived. All these factors will be present to varying degrees on extended space missions, with confinement being the most constant problem. Weightlessness may potentiate difficulties of adjustment and performance.

Reports from prisoners of war, men alone at sea or in solitary confinement, and the first experimental investigations at McGill University (e.g., Bexton *et al.*, 1954) encouraged the view that sensory and perceptual deprivation are powerful methods for producing systematic alterations in cognitive processes, perception, personality, and motivation in man. However, the results in what is now a fairly extensive experimental literature have not entirely confirmed this expectation. It is clear that the performance of isolated volunteers is not always impaired. In fact, there is evidence that immediate memory span (Myers *et al.*, 1964), vigilance (Smith *et al.*, 1967), complex perceptual-motor skills (Smith and Myers, 1967), verbal learning (Vernon and Hoffman, 1956), and sensory acuity (Zubek, 1969b) may actually improve during isolation, and relatively complex mental functions have shown little, if any, systematic decline. In general, the striking alterations in perceptual organization (e.g., the bending of plane surfaces and loss of perceptual constancies) first reported by the McGill investigators have not been found in later studies. On the other hand, severe monotony is subjectively stressful. The isolated volunteer finds isolation difficult to endure, is tempted to resign from the study, and seldom offers to repeat the experience. He reports extreme boredom, restlessness, anxiety, feelings of unreality, temporal disorientation, uncertainty about the boundary of sleep and waking, and vivid visual imagery.

MOTIVATION

In a number of studies (Murphy *et al.*, 1962; Smith *et al.*, 1962; Vernon and McGill, 1960), it has been found that early subjective and behavioral responses predict tolerance for isolation. Subjects

who become exceedingly bored and restless in the early stages of confinement are likely to be early dropouts from a lengthy study. Vernon and McGill found that early withdrawal could be predicted from the frequency of utilization of a viewing box in which dimly represented geometric shapes were displayed. The Antarctic studies (Gunderson, 1963; Gunderson and Nelson, 1963) as well as submarine patrols (Weybrew, 1961, 1963) indicate that monotony and boredom can be significant problems and that during periods of boredom various somatic complaints such as headaches increase in frequency. Weybrew observed that during the 83-day cruise of the USS *Triton,* motivation and morale declined after about ten days of confinement, a trend that continued throughout the voyage. Rather surprisingly, morale appeared to be higher on days such as Sunday when activities were less controlled and regimented.

Smith (1969), in his summary of the behavior of small groups in confinement, notes that several investigators have reported declining motivation throughout prolonged confinement even among initially highly motivated personnel. Such changes in morale can often be attributed to situational factors such as poor leadership, crew conflicts, task monotony, and diet, but Zubek and Welch (1963) and Zubek *et al.* (1969a) have interesting evidence for a psychophysiological correlate of low motivation. They repeatedly have found a systematic decrease in the frequency of the electroencephalographic (EEG) alpha rhythm during prolonged exposure to monotonous environments, and they report that motivational losses such as inability to study or engage in sustained purposeful activity are associated with the magnitude of this EEG change. The slowing of the EEG alpha waves persisted for as long as seven days after a 14-day exposure to unpatterned light and white noise in a confinement setting. Some subjects continued to feel apathetic, disinterested, and unable to "get started doing anything" throughout this period of slowed EEG. The state of consciousness of these subjects is not really understood. Slowing of the alpha rhythm might simply reflect a drowsy state not conducive to high levels of motivation or interest in cognitive activities. If so, it is indeed a paradox that vigilance, memory, and even complex intellectual operations are not impaired and may actually show improvement during confinement. It is possible that any new and sporadic activity, such as a test of performance, during a period of confined boredom and depression may be sufficiently arousing and rewarding to improve greatly, at least temporarily, the motivational state and the performance of the subject. Zubek's data are based on single isolated subjects; the studies should be repeated with confined groups, taking this motivational aspect of testing into consideration. This topic is discussed further in this chapter under Central- and Autonomic-Nervous-System Indices.

The mechanisms for ensuring continuing high levels of motivation including selection, leadership, group dynamics, recreation, exercise, work assignments, food, various environmental factors, and the like will be considered in other chapters of this report. Most of these factors are also important for sustaining performance in the sleep-deprived subject. In fact, the early effects of sleep deprivation (including lapses) may be due primarily to loss of motivation rather than to physiological impairment. For example, Wilkinson (1961) found that "interesting" complex tasks could be performed efficiently after a night without sleep, and feedback in the form of knowledge of results prevented decrement on lengthy continuous monitoring tasks.

Motivation for crew members should not be a problem, at least for the first long flights, and individuals who cannot tolerate long confinement will be eliminated during training. Problems of leadership and interpersonal conflict should also be apparent during training and corrected at that time. Very little is known, however, about optimal techniques for reducing monotony and boredom during long periods of group confinement. Obviously, there is a need for planning, testing, and simulating varieties of vehicle environments, task distributions, and off-duty individual and group activities.

COGNITIVE FACTORS

Although most isolated subjects report increasing difficulty with concentration, thinking, and memory, and although involvement in intellectual tasks such as reading and studying is low, measured performance has not shown consistent impairment. Smith (1969) concluded that "persons undergoing group confinement generally seem to be able to maintain their abilities, although there are some reported instances of skill decrements perhaps when cramping is severe." As noted above, studies of the intellectual functions necessary for reasoning, numerical computation, verbal learning, memory, complex perception, and communication have found no evidence of decrement for confinement periods up to one week (Zubek, 1969b; Hanna and Gaito, 1960) or two weeks (Hammes, 1964). Chiles *et al.* (1968)

found that men confined in an aircraft simulator and operating on unusual work–rest schedules could sustain optimal performance on complex tasks for as long as 30 days. Smith (1969) points out, however, that lack of control groups in most studies coupled with relatively short periods of confinement limit useful generalization from these experiments. The fact that most isolated and confined subjects feel that they have suffered impairment of intellectual functioning suggests that efficiency may be sustained at some cost to reserves and that much longer periods of confinement might cause measurable decrement. Clearly, there is a need for objective data on the performance of space-relevant tasks by well-motivated groups confined for extended periods. Skylab and subsequent missions will provide the opportunity to obtain needed data in actual flight through validation of performance on regular tasks and through preprogrammed tests.

SLEEP CHANGES

Disturbances of sleep have been an objective finding in several studies of isolated groups, and these effects increase with the duration of the isolation experience. That sleep is an area requiring attention is also demonstrated by the reports from astronauts of the longer Gemini and Apollo missions (Berry, 1970). Gunderson (1963) found that the most frequently reported symptoms during Antarctic expeditions were sleep disturbances and depression, and Mullin (1960) reported that insomnia was a widespread phenomenon during the dark, indoor, Antarctic winter season Disruption of sleep and prolonged insomnia were attributed to cumulative tension, reduced physical activity, group suggestibility, and intense desire for stimulation. Soviet studies of isolated groups have also reported changes in sleep patterns (Lebedinsky *et al.*, 1964). The symptoms of altered sleep found in confined groups are not limited to difficulty in falling or staying asleep. but may include periods of extreme drowsiness and lowered arousal similar to those found in studies of acute sleep deprivation. As in the isolation studies, sleep deprivation alters the EEG alpha rhythm, a change that is associated with specific lapses in performance on tasks that require sustained attention (Williams *et al.*, 1962).

Only one systematic study has been made of the effects of prolonged confinement on the EEG stages of sleep (Natani *et al.*, 1969). It was conducted on members of a wintering-over party at the South Pole Station. Besides extreme social isolation for nearly nine months, the group endured a unique combination of environmental factors, including high altitude, intense cold, very low humidity, and the absence of a 24-h light–dark cycle. From sleep logs and EEG data, these investigators concluded that men on the Antarctic station averaged about 7.5 h of sleep out of 24, the range being 5.6 to 10.5 h. Despite these relatively stable (and normal) mean durations of sleep, there also existed a particularly virulent form of insomnia commonly called the "Big Eye" (Siple, 1957). The most systematic and striking change in the EEG sleep profile was a progressive decrease in the amounts of stage 3 and stage 4 (slow-wave) sleep, alterations that were not reversed for at least six months following return to the United States. The functional significance of slow wave sleep is not known, but there are correlative studies that suggest that it is important for healthy psychophysiological functioning. For example, the altered sleep patterns found in depressive illness are characterized primarily by absence of slow-wave sleep (Mendels and Hawkins, 1967; Hawkins *et al.*, 1967). Also, subjects undergoing experimental deprivation of stage 4 sleep (Agnew *et al.*, 1967) reportedly developed the symptoms of a mild neurasthenic and depressive reaction. However, recent studies at the Navy's Medical Neuropsychiatric Research Unit in San Diego have not confirmed the latter effects. In those experiments, subjects were allowed differential recovery of EEG slow-wave or fast-wave sleep following 60 h of total sleep deprivation. No differential recuperative effects were found on either performance or neurological measures. Continuing investigation of the biological and psychological significance of the EEG stages of sleep should be encouraged.

Inflight EEG measurements in the U.S. manned program have been made only on Gemini 7 but are scheduled for the first Skylab 56-day mission. Automated onboard monitoring, recording, and analysis of EEG and EOG (electrooculographic) data, with near-real-time telemetry of results, are to be made on 21 specified nights on one crewman during regular 8-h sleep periods, with control runs preflight and postflight. Seven discrete states will be encoded: awake, four stages of sleep, rapid eye movements, and head movements. The recently developed "sleep cap," which contains the signal sensors, eliminates the need to preattach electrodes to the head: the cap is simply donned and does not interfere with the crew member. The EEG sleep measurements promise to be very valuable and should be extended to selected daytime activities as feasible.

SLEEP LOSS AND PERFORMANCE

Since progressive disturbance of sleep may be one consequence of prolonged confinement, it seems appropriate to examine possible impairments of performance as functions of sleep loss. This analysis must rely on the results of studies of acute sleep deprivation because there is very little information available on the effects of chronic sleep loss. For example, we do not know whether loss of some sleep every 24 h results in a cumulative sleep debt, nor whether sleep can be saved up ahead of time to sustain performance over a prolonged vigil.

With sleep loss, performance on certain critical tasks will eventually suffer (Johnson, 1969; Naitoh, 1969). In general, continuous, long-duration monitoring tasks, in which rate of data handling is paced by the information source rather than by the operator, are particularly sensitive to sleep loss. For example, Wilkinson (1968) found that vigilance and continuous addition tasks showed impairment if less than 3 h sleep had been obtained on the night before testing.

In their 1959 monograph, Williams, Lubin, and Goodnow proposed the lapse hypothesis to explain the impairments of performance found with sleep deprivation. Loss of sleep results in brief, intermittent lapses into deep drowsiness which increase in frequency and duration as the task and the vigil are prolonged and which are accompanied by EEG signs of light sleep. Long-lasting, work-paced monitoring, and computational and decision-making tasks that involve high information-processing requirements are particularly vulnerable to loss of sleep. There are, however, types of performance deficit with sleep loss that do not seem to result from intermittent physiological lapses. Notable among these is impairment of short-term memory. The moderately sleep-deprived subject can recall information acquired prior to sleep loss as well as a normal subject, but he has difficulty recalling the content of new messages, especially where successful performance depends on the integration of current with preceding information. Complex intellectual tasks such as problem solving and logical analysis have been resistant to sleep deprivation.

On long-duration missions it would seem that the following functions are illustrative of the tasks that the crew must be able to perform with alertness, speed, and accuracy: (1) Monitor and interpret information concerning vehicle operation, cabin, outside environment, and physiological status of personnel. These data must be communicated to earth accurately and frequently. (2) Repeatedly read values of thrust duration and direction into and from an on-board computer. (3) Recognize, interpret, and make decisions about unexpected and subtle changes in information patterns. (4) Reorient, change the course, and adjust the velocity of the vehicle. (5) Contribute to navigational data by taking accurate astronomical fixes of a complex type. (6) Trouble-shoot and repair breakdowns. (7) Perform scientific functions such as astronomical observations. Sleep loss is likely to impair the first three functions more than the last four, because the first three involve more or less continuous monitoring of displays in which critical signals demanding decisive action are rare. Thus, they resemble the vigilance tasks that have proven so sensitive to drowsy states. All operators will be superbly trained for vehicle operation, navigation, and vehicle repair, and the relatively short duration of these tasks should make them resistant to sleep loss or other adverse conditions of flight. The sensitivity of scientific tasks to drowsy states depends, of course, on the nature of the task and the degree to which data collection and analysis are automated.

The importance of specific EEG stages of sleep for the maintenance of psychophysiological efficiency is not yet understood. The early expectation that sufficient rapid-eye-movement (REM) sleep, associated with dreaming in man, would be critical for mental health has not been confirmed, and the notion that slow-wave sleep is critical for effective performance has not received general support in research to date (Webb, 1969; also, unpublished data, Navy Medical Neuropsychiatric Research Unit, San Diego). While the emphasis has usually been on effects of sleep loss, there are recent data indicating that "too much sleep" can also be detrimental to both performance and feeling state (Globus, 1969; Taub and Berger, 1969). Helping time to pass by prolonging one's usual sleep time does not appear to be the answer.

Instead of asking what kind of sleep is significant for health and efficiency, some sleep researchers are becoming concerned with the "goodness of sleep" (Monroe, 1967; Johnson *et al.*, 1970; Williams and Williams, 1966). Goodness of sleep is measured in terms of time to sleep onset, number of awakenings, number of body movements, number of changes in sleep stage, and total duration of sleep. Highly correlated with these indices of sleep are the duration and regularity of the REM–non-REM sleep cycles. In good sleepers, short periods

of REM occur every 90–100 min during the night. In poor sleepers, this cycle is disrupted, and the usual orderly progression from one sleep stage to another is not present.

TECHNIQUES FOR OBTAINING ADEQUATE SLEEP

In protracted missions, the ability to get adequate sleep would appear to be crucial. What are effective techniques to ensure good sleep? There have been several approaches, varying from symbolic rituals to drugs. Careful work by Kales *et al.* (1968) indicates that use of drugs to induce sleep must be approached with extreme caution. Most hypnotics change markedly the kind of sleep a person usually gets, often lead to drug hangovers, frequently lose their effectiveness with prolonged use, and may cause severe nightmares during withdrawal. There are at present no effective hypnotics whose side effects are entirely benign, and prospective candidates for inclusion in any medical kit must be carefully evaluated.

Of increasing interest is the use of feedback methods to control many physiological variables such as heart rate, respiration, blood pressure, muscle tension, and even brain waves. It is entirely appropriate that these techniques be investigated as possible means of treating sleep-onset insomnia or, perhaps more importantly, to enable a crew member to achieve rapid onset of sleep when his usual sleep–wakefulness pattern is not possible.

Evidence that muscle relaxation can be useful in dealing with sleep onset problems has been reported by Jacobson (1938). Stoyva (1969), in a review of this area, found that autogenic training as reported by Schultz (1960) claimed 80–85 percent success with insomniacs. Stoyva has noted in his own work that deep relaxation of the head muscles is especially likely to produce strong feelings of drowsiness.

In addition to muscle relaxation, ability to control one's EEG alpha activity may be important for sleep induction. The alpha state is a relaxed condition and is generally incompatible with vivid visual imagery. Most subjects describe the alpha state as that of a blank mind. The fact that the sleep onset problems are usually associated with an inability to relax one's muscles and an inability to switch off one's thoughts suggests that a combination of muscle relaxation and alpha control might be more effective than either alone. Techniques are available that would enable study of the efficiency of either approach alone or in combination.

While self-regulation of one's internal state may not be the only

approach to ensure sleep, we feel that research should be undertaken in this area. The ability to control one's internal state might also be important during periods of sustained stress, to speed the return of a state of physiological equilibrium after disruption, or to enhance periods of rest which at certain periods of the mission may be brief.

If it is impossible to ensure proper sleep, then what are the signs of sleep loss, and how can these be detected? Naitoh (1969) concludes that this is not an easy task. Increasing errors of omission or delayed reactions on monitoring tasks are a likely occurrence, but under many conditions crew members can perform relatively well on tasks that are important to their survival even after two nights without sleep. Naitoh, after examining a variety of EEG, autonomic, biochemical, and behavioral variables, concluded that the best sleep-debt indicator was the quantity of the EEG alpha waves after eye closure. Closure of the eyes is normally accompanied by the appearance of alpha waves, and their absence, relative to the individual's normal EEG, reflects the extent of the sleep debt. In cases where it is not feasible to monitor EEG activity, and for those individuals who have low or no alpha activity, some type of routine task such as addition should be available to be performed in a scheduled manner in order to provide periodic checks on the possible accumulation of sleep loss.

If unavoidable, how can the effects of cumulative sleep loss and fatigue be minimized? The lapses due to sleep loss can be reduced by physical exercise, frequent changes of jobs, immediate feedback of error, warning signals (especially auditory) when dials approach critical levels, frequent rest periods, more than one observer on a display, increasing signal-to-noise ratios, and communication from stations outside the craft. If accuracy is essential but speed is not, then transforming a work-paced task to a self-paced one by taping the data is a helpful procedure.

WORK–REST CYCLES

The question of optimal work–rest cycles has not been resolved, either in the laboratory or in the Gemini and Apollo flights. Farrell and Smith (1964) reported that in a 30-day confinement mission their subjects felt that a fixed work–rest cycle, in which some crew members slept while others worked, served as a useful reducer of interpersonal contacts and associated tensions. Obviously, such a fixed pattern of work responsibility could lead to the formation of two or more subgroups whose goals and interests might eventually

conflict with over-all mission goals. Adams and Chiles (1960), Alluisi *et al.* (1963), Hartman and Cantrell (1967), and Chiles *et al.* (1968) all reported that rotating shifts which led to frequent disruption of circadian cycles were associated with irritability and some impairment of performance. Nevertheless, the data of Alluisi *et al.* (1963) suggested that with proper control of selection and motivational factors, crews could "work effectively for periods of at least two weeks and probably longer using a schedule of 4 h on duty and 2 h off." Furthermore, crews could "work even more effectively for periods of at least a month and quite probably for 2 or 3 months using a schedule of 4 h on duty and 4 h off" (p. *iii*). In general, morale remained relatively constant and high throughout the 30-day period of confinement, and irritability among crew members was confined to the early phases during which there were complaints of sleepiness and fatigue. Under routine conditions, for at least a month, performance on the 4-h-on, 2-h-off schedule was as efficient as that on the 4-h-on, 4-h-off system. However, efficiency on the former schedule was sustained only at a significant cost to reserves for meeting such challenges as acute sleep deprivation. Berry (1970) reported that astronauts have experienced difficulty in attaining good and adequate sleep in space. Various conditions contributed to this, including thruster-firing noises, communications and movement within the capsule, staggered work–sleep periods, strange and uncomfortable sleep conditions in the capsule or the lunar module, tension, and excitement. Simultaneous sleep periods seemed to work better than staggered ones.

Most studies of around-the-clock performance have found periodicities in performance functions that paralleled the circadian physiological cycle. It is well known that the circadian cycle is rather well reflected by body temperature. Depending upon an individual's daily schedule of activity, the plotting of hourly temperature readings for a 24-h period reveals a monophasic (sometimes diphasic) cycle, with maximum temperatures during the regular period of wakefulness and minimum during normal sleep hours. The most common type of daily temperature curve seems to be one that rises in the morning, falls slightly in the afternoon or evening, and reaches a low point between midnight and dawn. When a highly motivated volunteer is required to perform an exacting task demanding vigilance and judgment for 24 h (Hauty, 1959; Chiles *et al.*, 1968), the resulting performance curve looks very much like the body-temperature curve, the sharpest decline being seen during normal sleeping periods.

Despite the fact that Chiles and co-workers were able to modify this relationship by special motivational instructions, it appears that in the long run we are committed to this rhythm. It can be shifted or reversed in phase but not eliminated. Shifting or inversion of the day–night cycle is relatively easy, such shifts requiring several days to a week to achieve. The time for adaptation may be in part a function of chronological age, with younger subjects adapting more rapidly. Some physiological and behavioral circadian functions may take much longer to shift than others. Lindsley *et al.* (1964) found that the daily activity period of monkeys reared in darkness except for an hour of diffuse illumination per day tended to anchor itself to the regularly recurring light period. When the light period was shifted, the activity period did not shift immediately; it required from four to six weeks to take up its new location and stabilize there.

There is evidence that wakefulness cycles differ markedly across individuals (Kleitman and Kleitman, 1953). Some subjects wake up wide-eyed and ready to function efficiently, while others may take 3 to 4 h to reach this state. Some subjects function best in the evening hours, while others function best in the morning. Marked differences in adaptability to altered work–rest cycles have also been demonstrated: some individuals adapt rapidly to unusual cycles, while others are either unable to adapt or do so with considerable difficulty. According to Kleitman, there is a high correlation between performance efficiency and adaptability to the altered cycle as measured from physiological response systems. Hauty (1969) found that with prolonged performance, some tasks showed more decrement than others during low-temperature periods. Greatest deterioration in efficiency occurred in visual vigilance and radar reconnaissance tasks, while impairment was less marked in problem-solving and discrimination tasks.

Good experimental data are still needed to establish optimal work–rest distributions for various crew sizes. It is clear that a man's psychophysiological efficiency is normally highest at the peak of his circadian temperature cycle. However, essential data on the relative advantage of such distribution of work–sleep cycles, measured against its possible adverse effects on morale, do not exist.

A general recommendation would be that as far as is feasible crew members should maintain their usual sleep–wakefulness cycles whether this be one of 6 or 10 h of sleep. Sleep onset should be at the usual earth time. If a 24-h schedule is to be maintained, it is obviously impossible for each crew member to maintain his usual time

of sleep onset, and it may be useful to adapt crew members to different circadian cycles prior to the voyage and to maintain these cycles for substantial periods in flight. As indicated earlier, the work-rest schedule will have ramifications with respect to group dynamics, to individual psychological status, and, of course, to the individual's biological rhythms. The size of the crew will also be an important factor in determining the new schedule. However, to avoid the development of isolated subgroups it would seem undesirable to have a fixed schedule for the entire mission. One suggestion for scheduling would be to have a crew member who is undergoing transition to a new shift stand watch with a member already shifted. When the new member has adapted to the new schedule, the relief can be made. If crew and competence permit such overlapping schedules then there would never be watches manned only by crew members undergoing transitions in their biological rhythms.

In selection of crews for long-duration missions, the utilization of physiological measures such as internal and surface body temperature, heart rate, electrodermal activity, peripheral and central vascular activity, as well as measures of work efficiency, should be encouraged to identify individual patterns of circadian activity and adaptability to different sleep-wakefulness cycles among astronauts. Compatibility of the crew members in these respects may well be important to the mission.

On long-duration missions, with long, quiet, and undemanding cruise phases, crew option with respect to sleep-work scheduling probably could and would be instituted. Except for emergencies and terminal points in the voyage, simultaneous sleeping of members of the crew might be permissible, and indications are that it would prove more satisfactory. Other factors such as weightlessness may lead, however, to desynchroneses of physiological rhythms, including sleep. Other things being equal, it appears that attempts should be made to maintain a diurnal sleep cycle, when possible.

CENTRAL- AND AUTONOMIC-NERVOUS-SYSTEM INDICES

In attempting to anticipate the effects of prolonged spaceflight on the central nervous system (CNS) and the autonomic nervous system (ANS), it does not appear feasible at the present time to extrapolate from existing spaceflight data. Few data are available on changes in the EEG in man during spaceflight. Similarly, aside from

electrocardiograms, measures of respiration, and limited data on body temperature and blood pressure, almost no recordings of other parameters of ANS activity have been made during flight, measurements being confined to preflight and postflight physical examinations. This section thus relies heavily on studies of the effect of sensory and perceptual deprivation, isolation, and monotony on EEG and autonomic physiological measurements on the theory that prolonged spaceflight will be associated with reduction of environmental inputs. However, whether lowered gravity should be considered a reduction in sensory input or a change in sensory input has significant implications for this discussion and cannot be determined from available information.

EFFECTS OF SOCIAL ISOLATION AND PERCEPTUAL DEPRIVATION ON THE EEG

A series of studies by Zubek *et al.* (1961, 1963b; Zubek and Welch, 1963) and others (Heron, 1961; Mendelson *et al.*, 1961), have elaborated the relatively consistent observation that alpha activity of the occipital area is altered by social isolation and perceptual deprivation. The change is one of a lowering in average alpha wave frequency, with the amount of lowering related to degree and length of the deprivation experience. The longer the deprivation lasts, the lower the dominant alpha frequency falls. Recovery from such deprivation has not been so well studied. Most studies provided for only short-term follow-ups (less than one week), and recovery to resting alpha frequency was not complete in this time. Zubek *et al.* (1961) report that alpha activity returned to a basal level during a two-week follow-up, although temporal lobe theta activity was still in evidence. Zubek (1969b) suggests that the results of his earlier studies demonstrated that *perceptual isolation* produces a greater lowering of alpha frequency recorded from occipital derivations than an equal period of *sensory deprivation* (1.21 versus 0.85 cps). Incidence of theta activity, particularly as measured from temporal derivations, was equally affected by these two types of deprivation.

Lebedinsky and colleagues (quoted in Zubek, 1969b) have conducted social isolation studies for periods up to 120 days. These investigators also report lowering of alpha frequency, with the amount of lowering increasing as a function of duration of deprivation. They have reported EEG abnormalities to persist for more than 60 days after a 60-day period of social isolation. Of special interest in many

of the Russian studies is the fact that subjects are not restricted with respect to movement. They live in a simulated spacecraft environment with minimal communication with the "outside world." Results of these studies are consistent with Zubek's EEG findings that both EEG abnormalities and behavioral deficits (reduced ability for sustained work, easy fatigability, changes in sleep pattern) persisted for long periods following the social isolation situation.

Less attention has been given to EEG patterns elaborated from the temporal area of the brain; the few results available suggest an increase in theta activity there. Frontal cortical sites appear not to have been investigated.

Methodologically most of the above studies have been quite primitive. EEG's have either been "eyeballed" or the frequency measured manually with a ruler.

In view of the findings that average alpha frequency is lowered under deprivation and the suggestion that this lowering is correlated with depression of cognitive efficiency, it seems surprising that more refined studies of EEG phenomena have not been conducted. Further studies should be undertaken to substantiate the relationship between cognitive efficiency and alpha frequency. Such studies could range from evaluating dominant alpha frequencies associated with drop-off in performance and errors in a continuous performance task to studies in which task presentation is contingent on the presence of specified alpha frequencies. The task should again vary in complexity from simple to complex decision-making. The studies reviewed have not attempted to assess directly the relationship between dominant alpha frequency and cognitive efficiency. They have all been correlational in nature, with time periods of sampling of EEG and measurement of cognitive efficiency occurring at different points in time. It is thus suggested that some priority be given to the conduct of studies in which these two sets of measures are evaluated concurrently.

That the alteration in cognitive performance with deprivation is not simply a function of drowsiness or lessened alertness, as might be inferred from the lowering of dominant alpha activity, is suggested by the fact that other measures of arousal suggest that subjects are in a hypervigilant state. Unfortunately, the studies in which electrodermal activity were measured did not also record EEG's. Vernon *et al.* (1961a) report decreases in skin resistance, with longer periods of deprivation (72 h) producing greater decreases than lesser periods of deprivation. Similar results are reported by Zuckerman *et al.* (1964). Not only do electrodermal measures suggest an increase in

arousal, but Davis (1959), measuring muscle tension and heart rate, found both measures to be significantly increased. In the absence of data in which EEG and other physiological measures were simultaneously recorded, we would cautiously suggest that the lowering of alpha activity associated with deprivation experiences not be taken as indicative of a lowering of arousal. It is quite possible that a number of mechanisms exist for lowering dominant alpha activity and that only one of them is associated with arousal. The pharmacological literature gives adequate evidence that isomorphism between alpha desynchronization and behavioral arousal is far from perfect.

Let us assume that the relation between alpha frequency and cognitive efficiency is real and that alpha frequency might be used as a predictor of cognitive efficiency. What types of study should be conducted to investigate this phenomenon further? With current computer technology (fast Fourier transform), it is quite feasible to obtain spectral analyses of EEG's with high resolution and short processing time, thus taking the drudgery out of the analysis and allowing for much finer resolution of average alpha activity.

Other measures of alpha activity might also be proposed. Pilot studies suggest that there are marked individual differences in stability of alpha activity with respect to amplitude (or energy) and frequency. For example, spectral analyses of successive 10-sec periods of occipital EEG indicate that some subjects have extremely frequency-stable alpha generators, their dominant alpha activity remaining restricted to a very narrow frequency band. One subject showed reasonably stable and narrow-bandwidth power spectra for four successive 10-sec periods. In contrast, another subject manifested a dominant alpha frequency which was in constant flux and ranged over a broad frequency band. Assuming that there is a continuum of alpha stability with these two subjects occupying relatively extreme positions on the continuum, could one predict which subject is more likely to demonstrate alpha-slowing when placed in a deprived environment? The answer to this question can be readily determined and might lead to the development of more refined selection procedures for identifying individuals who could work most effectively in such environments.

Other questions relating deprivation phenomena to shift in alpha frequency can be asked, such as: During and following deprivation, does the entire spectrum of alpha activity shift downward, or is there selective enhancement of activity at a specific frequency? A third possibility is that the apparent downward shift of the dominant alpha

frequency from nine or ten to seven or eight per second is attributable to an increase in theta activity (five to eight per second) as has been reported for the temporal area.

If cognitive efficiency is lowered during periods of low-frequency alpha production, and if procedures are available to monitor and rapidly alter such alpha activity, an alpha monitor could be developed so that (a) important decisions are only made when dominant alpha is in an acceptable frequency band, or (b) alpha activity is brought into an acceptable frequency band before the subject is called upon to make important decisions.

Severity of the deprivation experience also appears to be a variable worthy of further investigation with respect to the development of predictors of response to prolonged deprivation. To the best of our knowledge no studies have been conducted along these lines principally because most investigators have been more concerned with demonstrating deprivation-induced deficits than in developing predictors. Zubek, as well as others, has shown that the severity of EEG and behavioral deficits as well as the speed at which they evolve are a function of the intensity of the deprivation experience. The more severe the deprivation experience, the more rapidly changes evolve. At one extreme the administration of Flaxedil (which is believed to exert its major effects at peripheral neuromuscular sites) produces EEG changes with great rapidity. Van Wulfften Palthe (1962), utilizing extremely severe sensory deprivation, generated EEG changes within an hour. Zubek and Welch (1963) manipulated degree of motor restriction and found that a group not exposed to exercise and a group given exercise were differentially affected by perceptual isolation, the exercise group demonstrating significantly less EEG alpha-slowing than the no-exercise group. It would seem feasible to run studies utilizing the same subjects and manipulating degree of deprivation to determine if a predictive relationship can be generated from a knowledge of how subjects respond when shifted from a given degree of deprivation to a more severe degree of deprivation.

Finally, there are data in the literature that suggest that the speed with which alpha-slowing occurs during deprivation is also affected by "set." The literature on set suggests that the greatest degree of EEG slowing occurs during the period immediately preceding termination of the deprivation experiment. Thus Saunders and Zubek (1967) demonstrated that subjects deprived for seven days, when compared with those perceptually deprived for 14 days, demonstrated a greater decrease in alpha frequency after seven days than was true at seven days for those expecting the 14-day deprivation experience. Similar results have been reported by Lebedinsky *et al.* (1964). These results suggest that instructing subjects that they will be exposed to a seven-day period of deprivation and at the end of that period asking them (or telling them) that they are expected to stay in the chamber for an additional period of time might be one procedure to speed up the development of EEG slowing, thus reducing the time required for test periods.

SYMMETRY OF CORTICAL ACTIVITY

Recordings of EEG activity from bilaterally symmetrical skull (brain) sites demonstrate considerable individual variability with respect to symmetry of spectral plots. One such plot shows the two sides quite symmetrical with respect to distribution of EEG frequencies. Another plot, from an equally normal subject, shows quite asymmetrical frequency spectra for the two symmetrical brain sites. The questions to be raised here are: Is bilateral symmetry or asymmetry predictive of EEG and cognitive responses to deprivation? Is one side of the occipital cortex (or other cortical sites) more responsive to such experiences than the other?

The above type of analysis neglects phase information. Two recordings from a subject may produce identical or very similar spectral density plots, but one tracing may be time-delayed with respect to the second tracing; i.e., there is a phase difference between the two signals. With correlational procedures, including product–moment correlations and coherence analysis, phase information can be readily evaluated and quantified. In many subjects alpha activity is reasonably coherent, while in some it is quite incoherent. Again, one can ask questions about the relationship between coherence of alpha activity and cognitive functioning, as well as questions pertaining to changes in coherence as a function of restrictive experiences.

MEASUREMENT OF CORTICAL INTEGRITY

One further measure of EEG activity deserves to be explored with respect to its implications for the evaluation of flight candidates and crews. This technique has been extensively used by Russian investiga-

tors to evaluate "cortical tone" or "cortical excitability" and the development of "cortical fatigue" or inhibition of cortical functioning (not to be confused with their concept of "cortical inhibition"), but it has aroused little or no interest in this country. The procedure involves evaluating changes in the occipital photic driving response as a function of duration of stimulation. Russian investigators (Sokolov, 1963) claim that the frequency at which the brain can be "driven" by photic stimulation is one index of cortical excitability. The higher the frequency at which 1:1 or higher harmonic driving can be obtained, the greater the "functional integrity" of the cortex and the greater its excitability. Evidence in support of this contention is drawn from the work of Pevzner (1961) with oligophrenic (feeble-minded) children, animal studies involving phylogenetic comparisons, and ontogenetic studies in man (Ellingson, 1964). Pevzner's material indicates that mentally defective children demonstrate poor photic driving, seldom attaining frequencies greater than 5 cps. Studies by Sokolov (1963) indicate that as one ascends the phylogenetic scale the frequency at which the organism demonstrates photic driving steadily increases; and Ellingson's data on newborns and infants suggest that photic driving is absent in the newborn and develops ontogenetically.

The second measure of functional integrity of the cortical "analyzer" deals with the inhibition of photic driving as a function of duration of stimulation. Using a Walter-type spectral analyzer, Sokolov reports that as a function of duration of stimulation one first sees a decrement in driving at higher harmonics of the frequency of stimulation with inhibition of driving at the frequency of stimulation evolving more slowly. Sokolov's neurophysiological interpretation of this phenomenon suggests that the effect is due to the development of "fatigue" in cortical cells, and that alteration of the driving response can be utilized as a measure of fatigability of the cortex.

ANS MEASUREMENTS DURING SOCIAL ISOLATION AND PERCEPTUAL DEPRIVATION

Autonomic measurements during isolation and deprivation have apparently been extremely limited. There are a few studies dealing with electrodermal phenomena and even fewer in which heart rate and muscle activity have been recorded. Equally unfortunate, no studies apparently have utilized autonomic and EEG recording concurrently.

The studies of autonomic activity generally show that initially subjects become drowsy and may even sleep or relax for the first few hours of the experiment. During this period, skin resistence rises, heart rate falls, and muscle tonus is decreased. After this time, there is a steady decrease in skin resistance and suggestive evidence for increases in heart rate. Measures of autonomic activity thus suggest that subjects tend to become more aroused as a function of duration of deprivation.

The results obtained in the EEG and electrodermal system are thus at variance. The EEG indicates a decrease in alertness (with perhaps concurrent deficits in performance on cognitive tasks), while an increase in alertness is measured in the electrodermal system (lowering of resting level of resistance and increase in nonspecific responses). One hypothesis to reconcile this difference is that the EEG measurements may reflect principally changes in the cerebral cortex (occipital and temporal areas), while the electrodermal changes are more sensitive to alterations in brain activity further down, perhaps at the level of the reticular formation.

Apparently, peripheral vascular activity has not been recorded in these experiments. This would seem to be an extremely important physiological measure to those concerned with cardiac decompensatory phenomena associated with long periods of exposure to 0 *g*. A number of techniques for recording such activity is available, including photoelectric plethysmography (Hertzman, 1937), strain-gauge plethysmography (Whitney, 1953), impedance plethysmography (Nyboer, 1959), and capacitance plethysmography (Figar, 1959). The last technique has special appeal because it places no mechanical or thermal restraints on the limb or body part from which one is recording. With photoelectric plethysmography, some skin warming occurs which produces compensatory responses in the peripheral vasculature. Strain-gauge plethysmography as well as capacitance plethysmography to some degree constrict the limb or phalange from which recordings are to be taken. (This appears to exert its major effect on the ability to record vasodilation responses; constriction responses are much less affected.) Whichever technique is selected, it would appear important to evaluate the effect of varying durations of weightlessness on both peripheral vascular activity (skin) and on vascular supply to muscle. Such recordings should be taken under conditions of rest, following exercise, and in response to sensory stimulation. They may well be useful in determining the amount

and type of exercise astronauts should engage in during long-duration missions.

UTILIZATION OF CNS AND ANS INDICES IN CREW SELECTION AND TRAINING

A number of measurements and experiments on motivation, cognition, and sleep–work factors have been suggested in earlier sections of this chapter. The following are offered in addition.

Zubek (1964) has presented data indicating considerable individual differences with respect to decrease in EEG alpha frequency as a function of duration of deprivation and has correlated the degree of alpha slowing with impairment of performance of a variety of tasks. He interprets the impairment as being due to motivational deficits, having found a correlation of 0.67 between EEG slowing and his measure of motivational deficit. This again suggests the possible utility of using EEG recordings during experimental deprivation as a tool for the selection of astronauts who demonstrate the least amount of alpha-slowing and presumably could be counted on to maintain a higher level of task-oriented behavior than those who demonstrate greater degrees of alpha-slowing.

Should it become desirable or necessary to monitor level of alertness in astronauts, the following approach may be the most efficient. There are considerable data available in the literature that indicate marked individual differences with respect to the physiological response system that shows the greatest change as a subject passes from a state of high alertness through restful alertness to sleep. In some subjects electrodermal measures are most sensitive to changes in alertness, while for others the EEG or cardiac measures might be most sensitive. Subjects are quite consistent or reliable with respect to the response system most sensitive to changes in state. The system in which a given crew member is most sensitive can be determined during training and the necessary instrumentation devised to monitor this system in him.

According to Zubek (1969b, p. 262), Soviet researchers report that the deleterious effects on EEG and performance produced by social isolation can be reduced by "prior exposure to isolation, performance of a special set of physical exercises, certain work-cycles, engaging in useful work,' and the use of an enriched vitamin diet. Unfortunately, no details are given on the types of exercises and diet that were employed." A few studies in the U.S. literature also suggest that prior

deprivation experiences may serve a protective function against both EEG and behavioral deficits (Leiderman, 1962; Zubek *et al.*, 1962).

RECOMMENDATIONS

1. The long-term effects of spaceflight on cognitive functioning are clearly of first importance to mission success and cannot be predicted from existing data or theory. Ground-based experiments, and the definitive measurements in space, should emphasize evaluations of operational performance and psychological measurements (attention, vigilance, perception, memory, learning, thinking, and judgment) in conjunction with physiological measurements of the reactivity and level of the central nervous system (electroencephalogram, average evoked potentials, and contingent negative variation or slow potential shifts) and the autonomic nervous system (heart rate, blood pressure, respiration, skin temperature, galvanic skin response). The physiological measurements, and especially the electrophysiological recordings of cerebral electrical activity, provide independent parameters on psychological and behavioral responses. They are also indicative of psychological and physiological states, constituting important control measures for such factors as arousal, activation, or vigilance while tests are in progress and as indicators of longer-term states during the course of the mission. Where possible, on-line results should be available for immediate study by the astronaut undergoing tests or by one of his fellow astronauts.

2. Continued ground-based research is needed on work–rest schedules, sleep, quality of sleep, methods of inducing and regulating sleep, methods of monitoring wakefulness and alertness, relation of sleep loss to performance efficiency, and countermeasures to sleep loss, monotony, and boredom. Emphasis should be on the study of physiological indicators of central neural functioning (electroencephalogram), autonomic neural functioning (various indices), and neuromuscular activity (electromyogram), during wakefulness and sleep and in relation to psychological tests and performance efficiency.

3. Work–rest cycles developed for long-duration missions must take into consideration optimal sleep schedules and other biological rhythms, group dynamics, and morale. Maintenance of usual terrestrial sleep–wakefulness cycles, simultaneous sleep periods, [illegible]d compatibility of crew members with regard to circadian rhythm[illegible] are

advised. Preflight training of astronauts and crews should include flight simulations in confinement and isolation, with appropriate operational tasks, sensory stimulation, work–rest schedules, waking- and sleep-state monitoring, and measurement of brain electrical activity (electroencephalogram), autonomic indices, and muscle tension (electromyogram). These data will serve as a baseline and as indicators of potential difficulties.

4. Adequate sleep on long-duration missions is most important. Nevertheless, sleep-inducing drugs or hypnotics must be used with great caution because of side effects. A more promising and healthful approach, not only to the control and attainment of optimal sleep but also to the regulation of waking states of relaxation and alertness when needed, is through conditioning and learning techniques. These procedures should be directed toward control of physical, physiological, and mental states involving muscular relaxation and regulation of activity of the central and autonomic nervous systems. Where sleep cannot be regulated properly, the effects of sleep loss must be combatted by countermeasures planned in advance. These would include exercise, frequent changes of tasks, frequent rest periods, and automatic control and warning devices.

5. Further study must be devoted to the determination of the significance of physiological changes during confinement and isolation, such as reduced alpha-wave frequency and its relationship to cognitive functioning. The possibility that alpha activity can serve as a predictor of cognitive functioning should be explored.

6. Insofar as feasible, every opportunity in upcoming manned missions should be utilized to gain the physiological and psychological data essential to long-duration missions.